NORAD CONUS Fighter Basing

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Report Documentation Page

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Overview

- Client Information
- Problem Statement
- Documentation example
- Data
- Methodology
- Analysis and Way Forward

Our Client

- NORAD
  - North American Aerospace Defense Command
  - Founded May 12, 1958 as a joint effort between the US and Canada
  - Tasked with defending US and Canadian airspace
  - NORAD uses a network of satellites, ground-based radar, airborne radar and fighters to detect, intercept and engage any airborne threat to North America.
  - Our client: Mr. Peter Puhek, J84

Problem Statement

- Fighter basing optimization
  - 75 bases: AF bases, airports
  - 49 defended cities: Continental US (CONUS) state capitals & Washington DC
  - Minimize total distance from bases to cities
- Unclassified version
- Use Microsoft Office products to conduct an analysis.
  - Access database supplied by client
    - The database comes from last years project
    - Provide documentation
- Will provide a base for future projects.
- Designed to be easily modified to reflect real world situations

The Problem

- Continued from last year
- Plans to span multiple years – add more capability each year
- Excel-based solution
  - No non-Microsoft Office optimization program
  - Analysis including ALL possible solutions
    - From 1 to 75 bases utilized
  - Broader sensitivity analysis
  - Automation/integration

Database Documentation Example

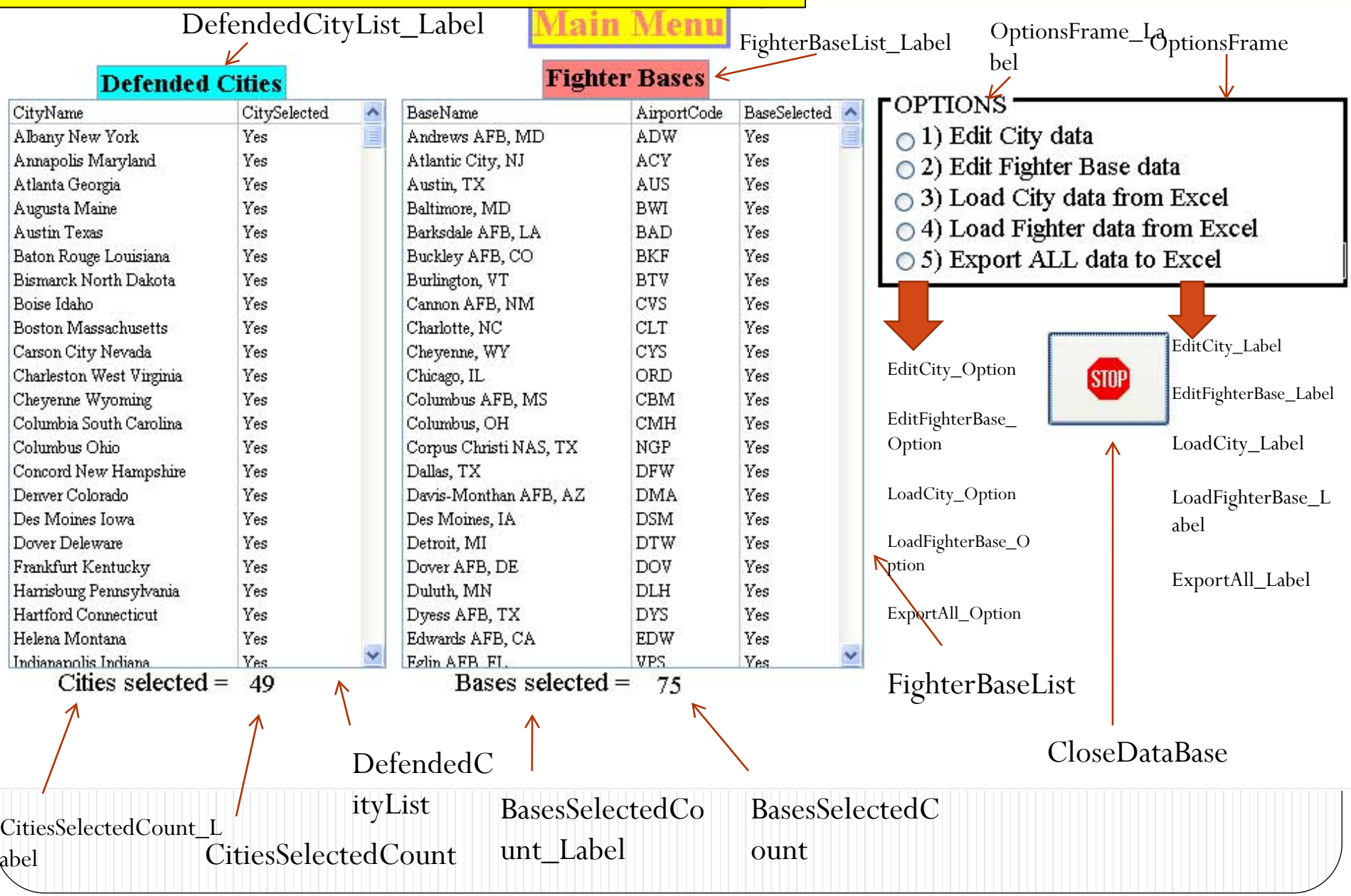
- Visual Basic Macro code is included in the Access database
- Makes database more user-friendly
- More complete in-line comments added throughout code

```
' Count selected cities.
  i = 0
  ' Initializes the counter, i, for the number of cities.

  If rst1.RecordCount > 0 Then
   ' RecordCount makes sure that the data set isn't empty.

    rst1.MoveFirst
    'This moves the program to the first record without applying a condition.
```

PowerPoint visual documentation created for continuity and new users



Data Collection and Manipulation

- Data Provided by Client
  - Latitude & Longitude of 49 cities and 75 bases
  - Verified using an Atlas
  - Small degree of error (center of city/base)
    - Makes of difference of 5-10 miles
    - < 1% of most pairs
- Spherical geometry calculates the distance
  - Assumes ellipsoid for these equations
  - Check Excel formulation vs. Vincenty equation
- Verification using 30 sample base/city pairs.
  - If significantly different, Team will reevaluate excel implementation of formula

Vincenty Equations

$$\alpha_1 = \arctan\left(\frac{\cos U_2 \sin\lambda}{\cos U_1 \sin U_2 - \sin U_1 \cos U_2 \cos\lambda}\right)$$

$$\alpha_2 = \arctan\left(\frac{\cos U_1 \sin\lambda}{-\sin U_1 \cos U_2 + \cos U_1 \sin U_2 \cos\lambda}\right)$$

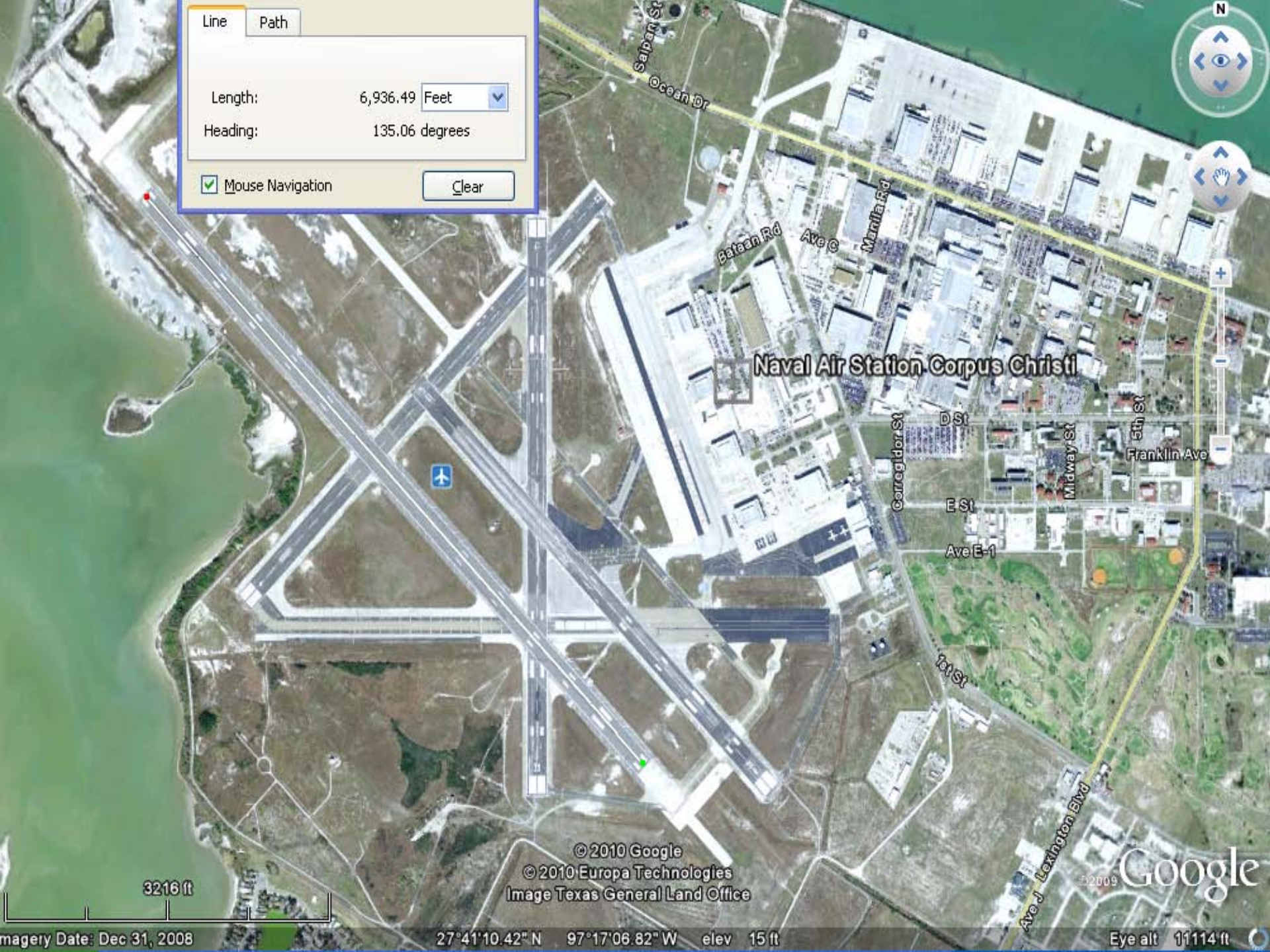
Alpha- Azimuth

U- Reduced latitudes

Lambda- differences in longitude

Reduction in Bases

- Objective Criteria
  - Runway length
  - Residential areas nearby
- Subjective Criteria
  - Infrastructure
    - Terminals, nearby roads
  - Proximity to capitol cities and other important targets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Mouse Navigation
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Saipan St
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Ave C
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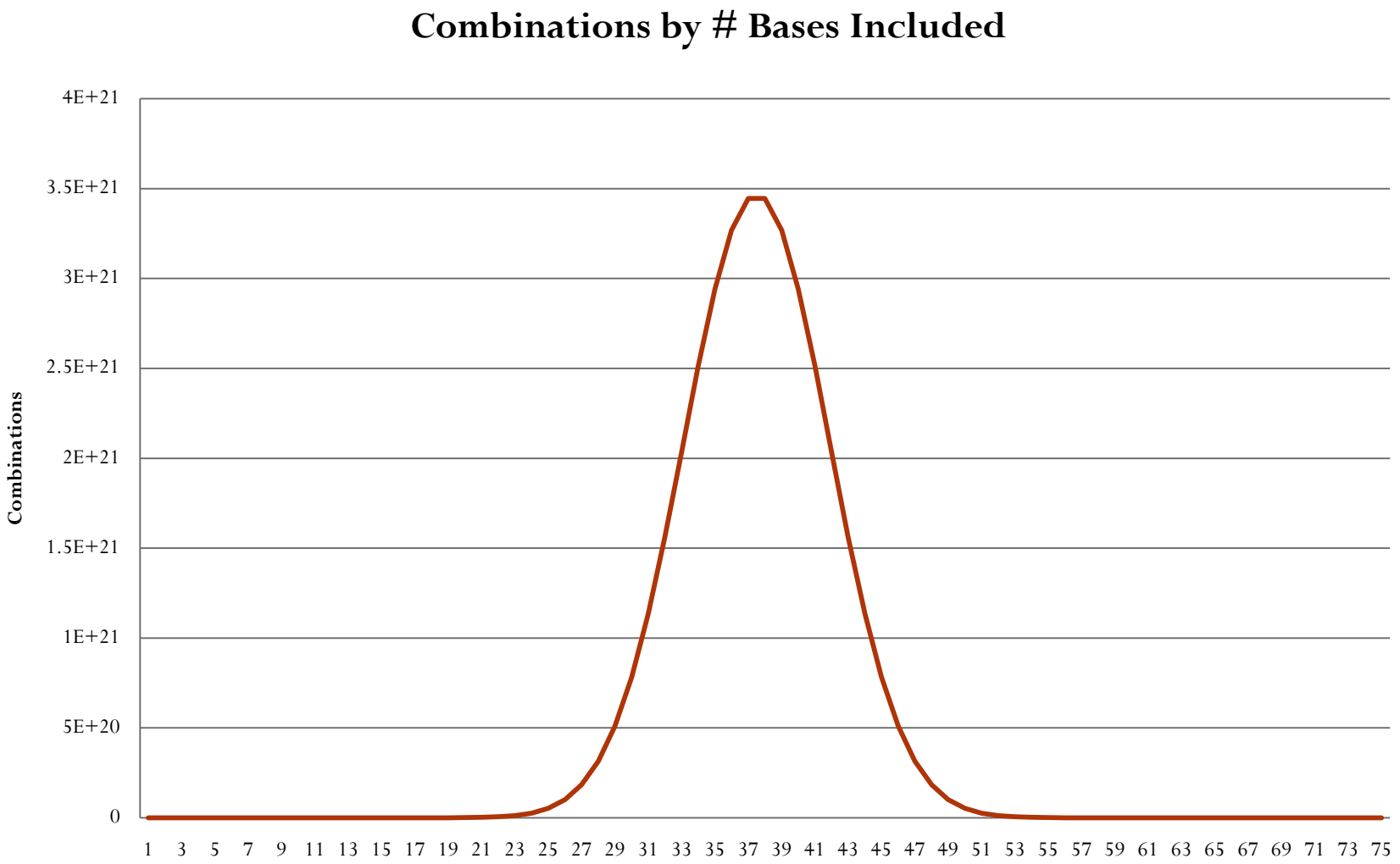
Naval Air Station Corpus Christi
D St
Corregidor St
Midway St
5th St
Franklin Ave
E St
Ave E-1
1st St
Ave J
Lexington Blvd
© 2010 Google
© 2010 Europa Technologies
Image Texas General Land Office
Google
3216 ft
Imagery Date: Dec 31, 2008
27°41'10.42" N 97°17'06.82" W elev 15 ft
Eye alt 11114 ft

Methodology – Initial Attempt

- The initial plan included a solution algorithm based on full enumeration

- After implementing an Excel Macro to solve for the 2-base solution, we began to suspect a problem (20+ min solution time)

Methodology - Combinations



Methodology – Initial Attempt

- The maximum number of combinations exceeds $3.4*10^{21}$
- This would require greater than a lifetime to solve, given current computational power
- Since complete enumeration is intractable, we must reduce the solution space

Methodology - Revised

- After consulting our client, we decided to formulate the problem as an Integer Program
- We formulated an IP in Excel and used Premium Solver V9.6 to find solutions
- We thought Premium Solver would significantly reduce the solution space through branching and bounding, but it does not
- The IP is only useful when small numbers of bases are included

Methodology – IP Formulation

Distance Matrix					
	Potential Bases				
Defended Cities	1	2	3	4	5
1	866	1601	577	481	697
2	1306	281	1326	911	1822
3	722	1281	512	320	868
4	1460	312	1580	1378	2108
5	734	782	780	716	1300
6	816	2218	660	1331	192
7	779	2085	555	1136	45
8	1001	1729	705	568	719
9	809	1689	509	607	563
10	1142	588	1306	1301	1835

Methodology - IP Formulation

- Objective: Minimize the sum distance from each included base to each defended city.
  - The formulation sums 49 statements similar to =LARGE(distances, #bases included), one for each city.

- Constraints: Number of bases included, binary variables

- Decision variables are limited to 75 by creatively utilizing an Excel function which dynamically chooses which included base defends a particular city

Methodology - Heuristics

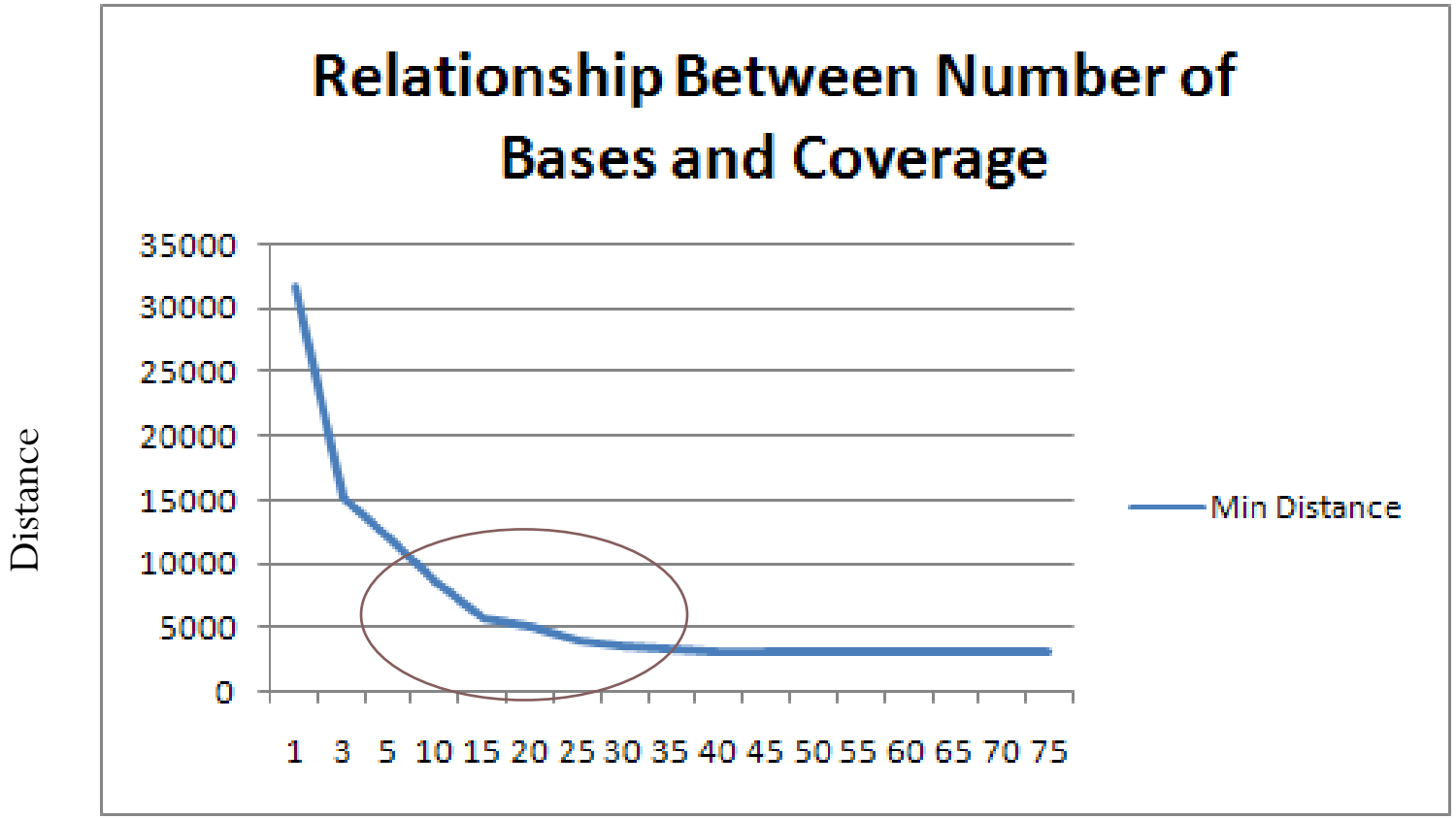
- Since the IP has proven to take too long, heuristics must be used to make recommendations when large numbers of bases are considered

- Through analysis, we were able to determine the global optimum solution, which includes 39 bases

- Next, implement a version of the Greedy algorithm
  - Should allow a very quick; although, sub-optimal solution
  - Will operate by removing bases from the global optimum choice, while minimizing distance penalties

Analysis and Way Forward

- Searching for the "Sweet Spot" based on decreasing returns



Analysis and Way Forward

- Final recommendation will include which base choices result in good solutions

- Recommendations will be made for 1 to 75 bases utilized

Questions?